A Low Cost Soft-Switched DC/DC Converter for Slid Oxide Fuel Cells

Monthly Report

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Prepared for

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1. Tasks Performed: Subtask 2.3 and 2.4.

Subtask 2.3: Design thermal management system

A. Thermal Subsystem Overview

To explain how the heat sink needs to be sized correctly, we use the Autocad drawing diagram for the final assembly, as shown in Figure 1, to indicate which components are located on top of the heat sink, and which are suspended in the air. The diagram was also shown in the last month's report. The power board and transformer sit directly on top of the heat sink, and a gate-driver board including gate drives and auxiliary power supplies is directly mounted on top of the power board to avoid any lead length introduced parasitic ringing. Thus any heat generated by the gate drive board needs to be removed by the exhaust fan. In the preliminary tests, the gate drive and the associated auxiliary power supply consume about 10 W, or 0.2% loss for 5-KW output load condition.

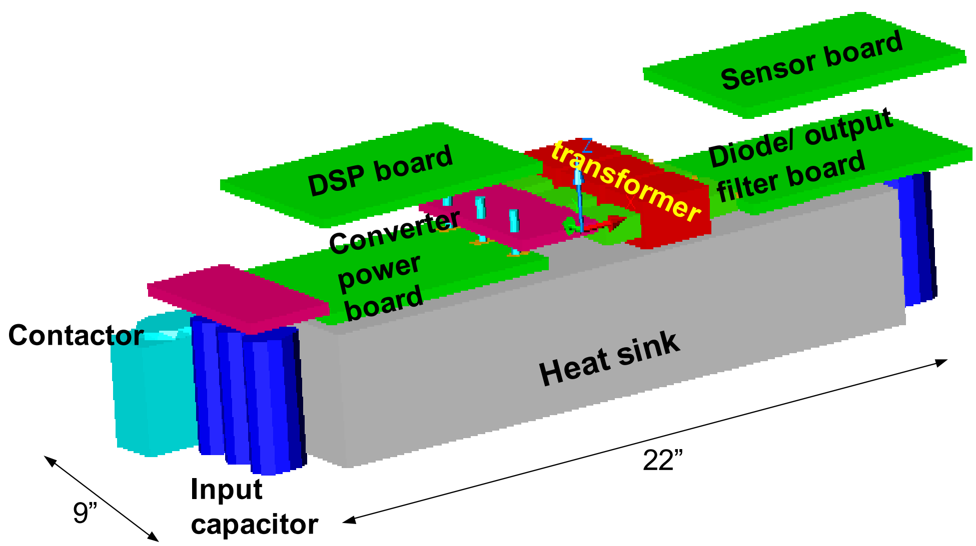


Figure 1. Autocad drawing for the planned final assembly of the entire dc/dc converter.

The theoretical planned worst-case efficiency of the power stage is 95%. Simple calculations indicate that a heat load of 300-W maximum occurs under the full power 6 kW condition, including 1 kW fuel cell parasitic load. This heat load is spread across the all devices, the output capacitors, transformer, and other losses in the PCB. The inductor, capacitor, control board, power supplies, fans, and other miscellaneous components will also consume power, but will not be cooled by heat sink. Thus, a total of 250 W needs to be removed from heat sink. A heat sink with sufficient volume should be enough to maintain safe operating temperatures. An exhaust fan can be used to keep the cabinet temperature low, but the heat sink should be designed sufficiently to handle the full-power operation.

B. Finite Element Analysis Simulation

Three major power loss blocks can be identified in Figure 1: (1) left-hand side power board that contains all the MOSFET devices, (2) middle transformers, and (3) right-hand side diodes. We selected a heat sink part number MF300T2125S2B made by R-Theta for the thermal calculation to see possible temperature rise condition. Using 40°C as the ambient temperature, the heat sink temperature under each block can be simulated with a finite element analysis (FEM) program. Figure 2 shows the simulation temperature distribution on the heat sink surface. Both centers of the power MOSFET board and diodes reach 79°C without any force-air cooling. This temperature may translate to 135°C device junction temperature for both power MOSFETs and diodes, and is not acceptable for long-term reliable operation.

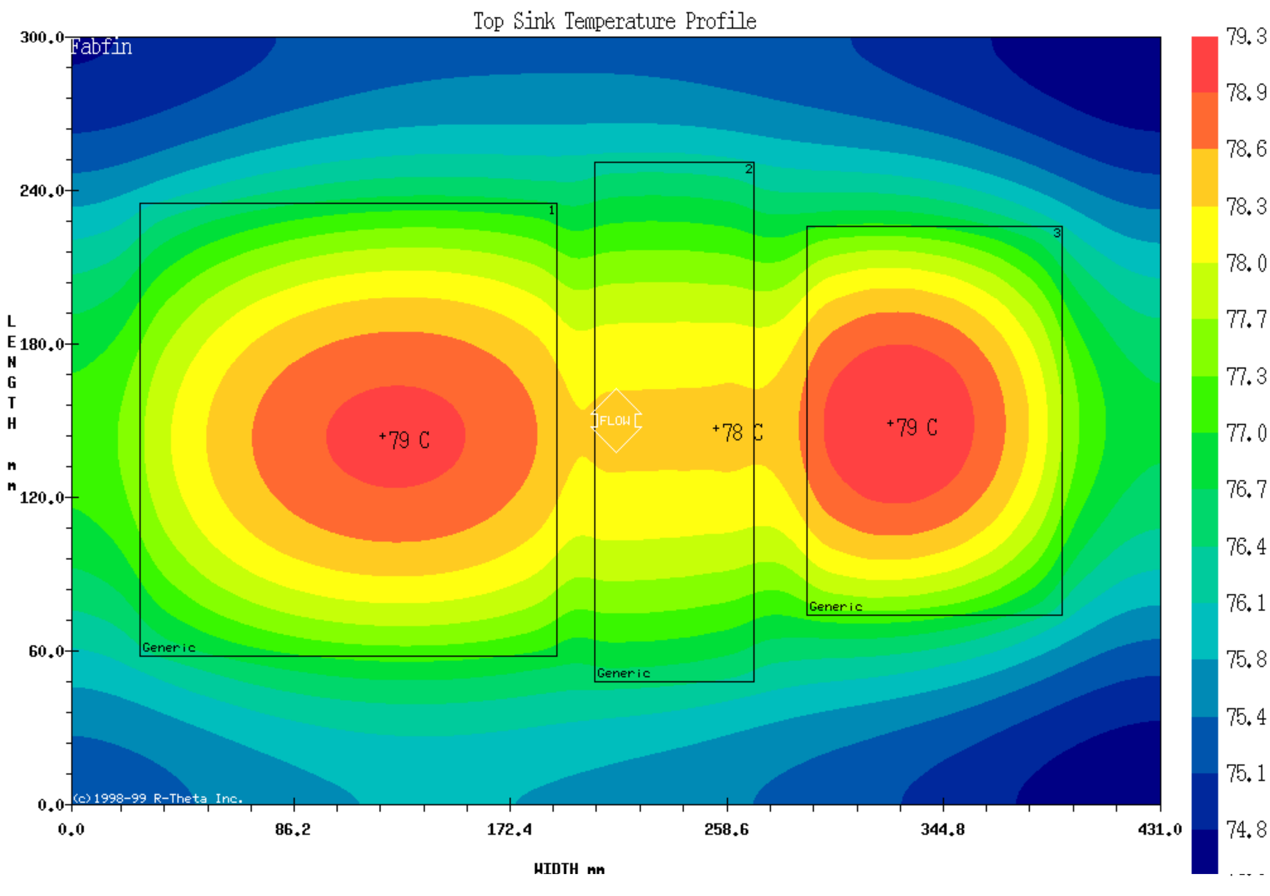


Figure 2. FEM simulation result for the selected heat sink.

The temperature can be significantly reduced with forced-air cooling. Figure 3 shows simulation results with 80-ft^3/min (CFM) forced-air cooling for the selected heat sink. The hot-spot temperature drops to less than 50°C. This heat sink case temperature can be translated to about 105°C junction temperature for the diode and 92°C for the power MOSFET, which is considered a safe and reliable operating region. With high efficiency requirement, power MOSFET should not be operated at a higher temperature condition. However, with increased cooling capability, the cost can be a concern.

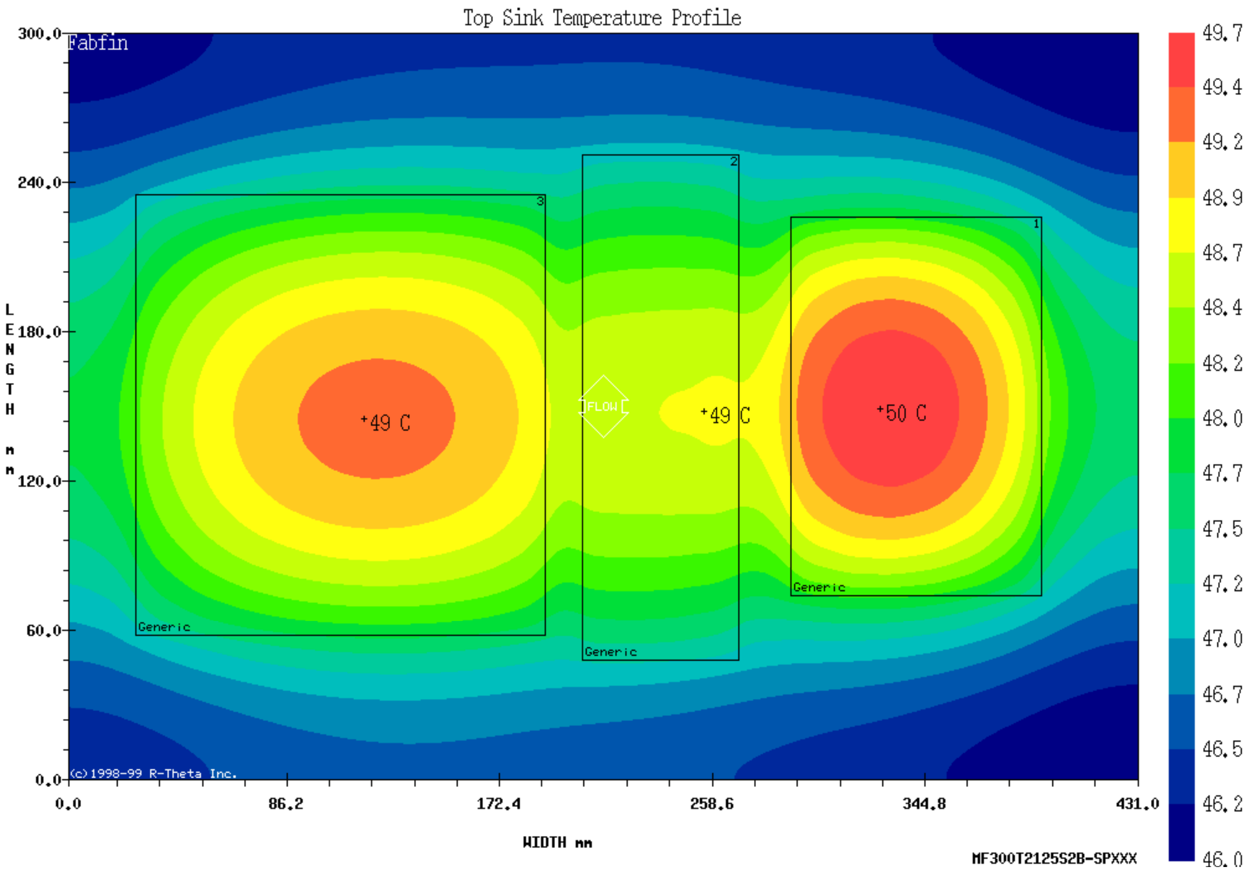


Figure 3. FEM simulation result with 80-CFM forced-air cooling for the selected heat sink.

<u>Subtask 2.4: Design and fabricate auxiliary power supply</u>

A. Specification of the Auxiliary Power Supply

For the three-phase converter circuit, we need a total of six gate drives and their associated isolated power supplies. The flyback converter is chosen for the auxiliary power supply because of its simple structure. Each isolated output in our design has a voltage of 15 V, and is further split into +10/–5 V for turning on and off the device. The negative voltage is needed to prevent noise trigger, and the positive voltage is chosen to minimize the MOSFET conducting voltage drop. The input of the flyback converter can be ranged from 20 to 50 V to meet SOFC voltage range. Overall, the specification of the auxiliary power supply can be summarized as follows.

Input: 20 to 50 V
Output 1: +10/–5 V
Output 2: +10/–5 V
Output 3: +10/–5 V
Output 4: +10/–5 V
Output 5: +10/–5 V
Output 6: +10/–5 V
Output 7: +5 V for DSP and control circuit power

B. Specification of Gate Drives

Figure 4 shows the block diagram of the entire gate drive and auxiliary power supply circuit board. The maximum power output of the flyback converter is 25 W. In our actual power test, the total gate drive power consumption was about 10 W, so the designed power level was sufficient.

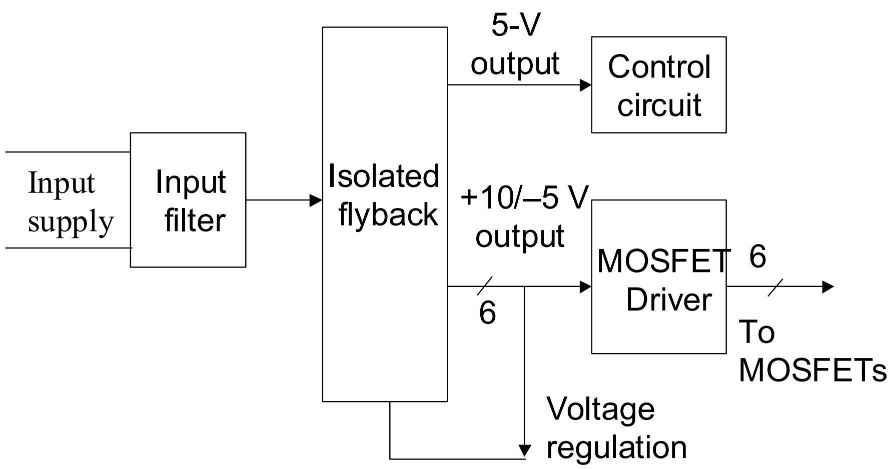


Figure 4. Block diagram of the gate drive and auxiliary power supply circuit board.

In order to provide reliable driving operation, the gate drive output needs to have high current capability. In our design, a 9-A_{pk} MOSFET gate driver was chosen. For each channel, the specification of gate drive circuit is listed as follows.

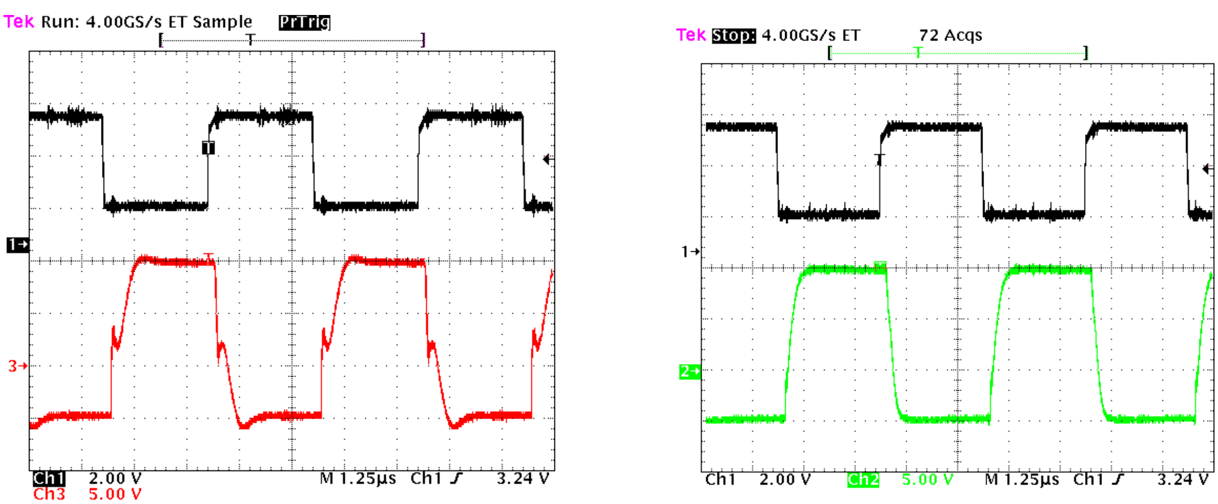
Input signal: 0 to 5 V TTL signal from DSP
Output signal: +10/–5 V with 9 A_{pk} capability

Figure 5 shows the completed gate drive and auxiliary power supply board. The flyback transformer has been internally designed and custom made for this application. The quantity price for this transformer is about $1.20 and is quite acceptable.

Figure 5. Completed gate drive and auxiliary power supply board.

C. Test Result

The gate drive board was tested initially with twisted wire pairs from gate output to MOSFET. It was found that the gate voltage was highly distorted. We then plugged the gate drive board on top of the MOSFET gates, the waveforms became clean. Figure 6 compares the gate drive waveforms with twisted wires and with direct plug-in. This proves that the parasitic ringing can be a problem without careful layout for this kind of power level.



(a) (b)

Figure 6. Gate drive output waveforms: (a) with twisted wires; (b) with direct plug-in.

After verifying reliable operation of the gate drive and power supply board, we power the entire DC/DC converter at the partial load condition. The input voltage was adjusted from 22 V to 30 V, and the output load was adjusted from 500 W to 1.5 kW. Figure 7 shows the test result with 22 V input, 1.5 kW output. The output voltage was split into two 210 V. The measured output voltage was 211 V each with less than 0.5% difference.

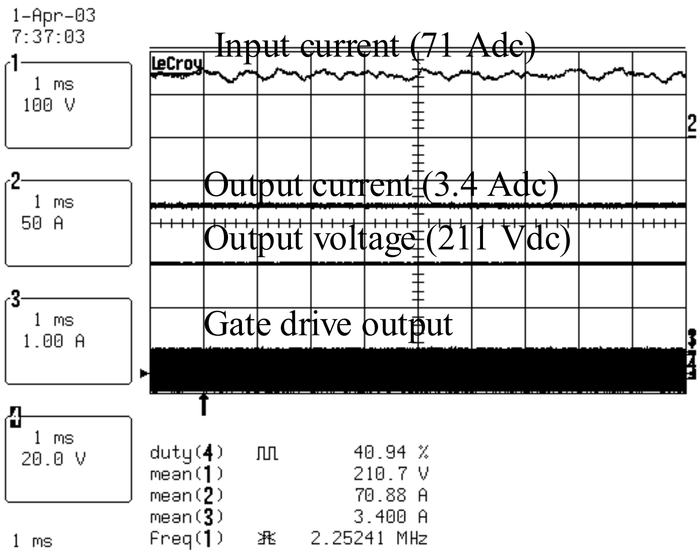


Figure 7. Measured gate drive output and voltage and current waveforms at 22 V input, 1.5 kW output condition.

It should be notice that in this design we eliminated expensive input high frequency capacitor and used only one-quarter sized output inductor as compared to our previously designed full-bridge DC/DC converter. With such dramatic reduction in passive components, the measured voltage and current waveforms are actually cleaner than the results obtained from the full-bridge version. The input current ripple is practically eliminated by the 3-phase interleaving structure, so the input filtering can be minimized. The output voltage and current maintain a clean DC for the resistive loads. The output inductor value is 80 μH. As compared to 330 μH that was used in the full-bridge converter output, this is not only a 4 times size reduction, but also a significant cost reduction and efficiency improvement.

Figure 8 shows the measured efficiency points as compared to the theoretical predicted points. The converter is currently running under hard-switching condition with partial loads, and the results match with the theoretical prediction reasonably well. To reach full power testing, we need to build additional load bank and use higher power supply source. We also need to mount the entire power stage on the heat sink we design, which should be ready for the next month's report.

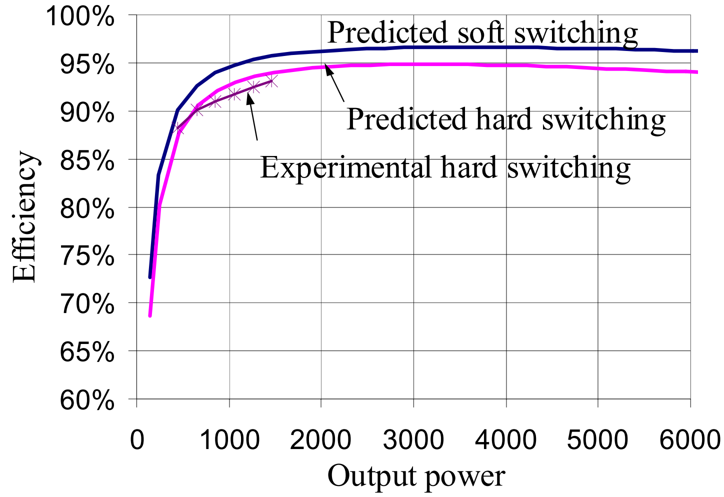


Figure 8. Measured efficiency as compared to the theoretically predicted efficiencies.

2. Key Milestone Update

The following table identifies key milestones that are completed and to be completed. The completed are marked with thick solid lines, and tasks to be completed are marked with dash lines. Although Subtasks 2.3 and 2.4 are considered completed, there will be an update with new heat sink installation for the measured temperature condition. Overall, we are slightly ahead of the scheduled milestone.

	Aug-02 Oct-02	Oct-02 Jan-02	Jan-02 Apr-02	Apr-02 Jul-03	Jul-03 Oct-03
1 Computer modeling and simulation					
2 Design Optimization 2.1 Power circuit 2.2 Magnetic components **2.3 Thermal management** **2.4 Auxiliary power supply**					
3 Design and Fabricate the Controller Circuit					
4 Integrate and Test the Alpha Version DC/DC Converter Prototype					
5 Test the DC/DC Converter with Fuel Cell Source					

3. Discussion Topics

Not applicable in this period.

4. Significant Accomplishments

The gate drive and auxiliary power supply board was completed, and the entire DC/DC converter has been successfully tested under open-loop condition.

5. Science & Technology Transfer

Not applicable in this period.

6. Presentation & Publications

Not applicable in this period.

7. Site Visits

Not applicable in this period.

8. Travel

Not applicable in this period.

9. Inventions

Not applicable in this period.